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SOLID WASTE COLLECTION COST ALGORITHM

By

Robert C. Porter

A Thesis

Presented to the Graduate Committee

of Lehigh University

in candidacy for the Degree of

Master of Science

in

Industrial Engineering

Lehigh University

1968

Certificate of Approval

This thesis is accepted and approved in partial fulfillment of the requirements for the degree of Master of Science.

July 15, 1968

Date

Wallace J. Richardson

Professor in Charge

Head of the Department

ABSTRACT

The solid waste disposal problem of the nation has become a matter of increasing concern to all of its citizens. The increasing costs of collection and disposal due to our exploding population and aesthetic and hygienic requirements now demanded are undergoing rigorous scrutiny.

This thesis presents in the form of an algorithm, a method for calculating the costs relating to the collection function of any present and/or proposed solid waste management systems. The algorithm defines a fexible, step-by-step system for analyzing costs so that it can be readily used by the staff of a muncipality.

The algorithm as herein defined has been applied in 20 different community situations of population variation of from 500 to 11,000 people. The algorithm has proven to give cost estimate results within plus or minus 15% in 15 out of 20 cases tested.

Acknowledgments

I would like to acknowledge the following individuals for the help and assistance they have given me during the writing of the following thesis.

Dr. Emanuel Averbach and Mr. Tom Klock for their editorial comment. Mr. Walter Fox, Mr. Herman Vollmar and many municipal officials too numerous to mention here for their assistance in providing the data required for the thesis. Professor Wallace J. Richardson my faculty advisor who helped guide me through the thesis work and Mrs. Carole Hockman and Mrs. Irene Lee who assisted in the typing of the work.

Robert C. Porter
July 12, 1968

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BACKGROUND OF THE PROBLEM

To the original plagues of mankind, symbolized by the Four Horseman of the Apocalypse; War, Famine, Pestilence and Death - we can now add a fifth one - Pollution. Pollution of our air, water and land - pollution that is caused by man's disregard of his environment and is now poisoning his environment.

Until man devised all of our modern conveniences and concentrated his living in permanent structures, Mother Nature was able to dilute most pollution to a level below the hazardous stage. Nature has now become a victim of man's devices, so that pollution is having significant adverse effects on man's supporting environment. Man has now come to the abrupt realization that if he is to reduce the amount of pollution in the air, water, and land, he must begin conserving his rapidly diminishing resources and prevent further contamination of them.

Pollution is attributable to many processes; among those of primary importance is that of disposing of waste products, ranging from wastes of the human life process to the unwanted remains of advancing technology and civilization. Man through the centuries has developed systems for disposing of human wastes, with some measure of proficiency, but the problem of dealing with solid wastes, such as domestic garbage and household trash, has presented a dilemma. Up to the time that men formed cohesive units and settled in cities with permanent structures, his answer to solid waste disposal was of no concern because of his ability to "walk away" and create another new solid waste disposal area for archaeologists to ponder over in years to come.

Through man's living in a concentrated fashion, the problem of solid waste has been magnified proportionately, with the typical solution having been that of the so-called "City Dump" on the edge of the urban center where unsightliness and burning were least objectionable. As man grew out from these urban centers he overran such "dumps", thereby requiring the development of other, more acceptable methods of solid waste disposal, such as the sanitary landfill. However, these methods have not met with complete scientific success or with wholehearted public acceptance.

Here in the United States, a country of great material wealth, solid waste disposal has always been of some concern. The problem has now reached the status of prime importance, with the need for disposing of over 800 million pounds of urban solid wastes and untold millions of pounds of agricultural and industrial solid wastes everyday.[1] In

[1] Mix, Sheldon A., "Solid Wastes: Every Day, Another 800 Million Pounds", Todays Health, American Medical Association, March, 1966

an article entitled "Where Will We Put All That Garbage", Fortune, October 1967, the lead statement relates: "Waste M anagement is suddenly a first-order problem and Nature has bucked it back to mankind." Many articles in such magazines as Civil Engineer, The American City, Business Week, News Week, Engineering News Record and such newspapers as the New York Times and the Philadelphia Inquirer carry articles regularly about the problem and progress towards its solution. They all indicate that the nation is beginning to face up to its sizeable problem in the field of waste disposal not only from where to put it but from the possible pollution effects after it has been put there.

With the President's signature on October 20, 1965, the Solid Waste Disposal Act of 1965 created a federal program directed toward solutions of the solid waste disposal problem. This has stimulated officials and community leaders to realize that solid waste disposal not only goes hand-in-hand with this civilization and its urban centers, but will increase in quantity as technology continues to move forward.

Since 1965 many research projects and studies have been initiated to investigate new methods for solving the many and varied solid waste disposal problems. One such experiment is being tried by the City of Philadelphia. They have been attempting to solve their solid waste dilemma through the use of "trash trains" that will transport Philadelphia solid waste from the city to strip mines in northeastern Pennsylvania. Another, the City of New York, is commencing to build a new $110 million dollar incinerator to alleviate its solid waste disposal problems.

In addition to the hygenic and aesthetic problems associated with the disposal of solid waste, there is a significant financial problem. The demands made upon the typical municipal budget are enormous, and the expenditures for better schools, greater police protection and increased welfare benefits are supported by well organized and vocal pressure groups. The New York and Memphis Citys' Sanitation Employees' strike, however, has demonstrated that waste disposal is also of compelling importance to a municipalities welfare. It was also demonstrated that money is an inherent part of such problems.

With this in mind, the problem facing most municipalities is the development of proper costs for the sanitation department budget. When requesting bids for collection services or developing a sanitation department budget, municipal officials need a guideline to follow. The form of guideline used has been an average cost per capita per day as obtained from o ther municipalities in the area.

Most of these guideline estimates of the collection cost per capita per day have come from past municipal budgets. They are obtained by dividing the collection budget by the estimated contributing population of the collection area. These are at best gross figures. They are peculiar to the communities from which they come and are not applicable to any other municipality.

In articles used as reference material (see bibliography), gross costs used are either a "national" average, or the costs derived by taking the total cost per year from the sanitation department budget (usually in a large city), and then dividing this by the cities' population. In assembling municipal figures for collection and disposal costs, a considerable range was discovered, with the collection figures varying from 1.50 up to 50.00 dollars (1) per person per year with an average of about $24.00.

The variation in the waste collection cost to a large extent stems from the lack of uniform definitions for the terminology used. For instance, the amount of waste per person per day may include that waste which occurs at work, play, school and business as well as that generated in the house.

The municipalities who do report solid waste figures add to the confusion through the lack of adequate measuring devices and definitions of solid waste. The lack of

(1) Costs developed from Federal Solid Waste Inventory Forms.

uniformity in reporting makes difficult the normal approach of the investigation; that is, there is no "data bank". One cannot obtain true comparative figures for collection and disposal of solid wastes by cubic yard or ton, handled municipality by municipality on a standard basis.

DEFINING THE AREA OF CONCERN

The sudden interest generated in the field of solid waste, because of the Solid Waste Disposal Act of 1965, is responsible for a general re-evaluation of all facets of the solid waste refuse field including collection, disposal and ways of calculating presant and projected quantities of refuse. Regional planners and engineers are now finding that they must come to grips with the problem when making land use and population projections, and solid waste disposal facility plans for expanding areas. This has been avoided in the past as there has been no real need to worry about the collection and disposal because convenient facilities were usually available. As a result, relatively little work has been done in the field of developing a scientific approach to the solid waste collection and disposal business.

M ost solid waste collection and disposal businesses have been conducted by private entrepreneurs who have run loose operations and have kept very few records. Customers were usually solicited on a catch-as-catch can basis often with little regard for efficiency. Many instances can be cited and still exist where a series of contractors service a single block, all collecting at different times. Cases are numerous of missed collections and abandoned route s without prior notification.

With the demand for more dependable collection and disposal services from the urban dweller, many communities have developed solid waste collection and disposal systems either as a municipal operation or by contract with a private agency. Many of the municipalities that have already ventured into the field are having difficulty in developing realistic budgets, because of the difficulty of transforming the number of households served into such quantities as; (a) the number of trucks, (b) men and routes needed, (c) the size of landfill required, (d) the quantity of solid waste materials that could or should be disposed of by other methods, such as combustion or composting.

THE PRESENT STATE OF THE ART

The first investigation made for this thesis was determining what basic research has been undertaken that is relevant to the estimation of collection costs. Various sources of material were reviewed and experts in the field were consulted. The results of this investigation showed that a limited amount of work has been done, and that some crude figures were available, computed on community averages. Direct measurements of individual household solid waste refuse output have not been documented. The best estimates now available are based on averages for a refuse truck route. It was very surprising that a majority of communities studied do not have reliable information about the weight and volume of solid waste that they handle. Where information is purported to be available, satisfactory cost breakdowns by collection area or pickup classification have not been made.

Some fairly good information is available about overall weight or gross volume of solid waste refuse collected in a few of the larger cities, but these include varying proportions of waste collected from commercial and industrial sources. An estimate of costs can be obtained from these municipal budgets.

Firmly established now, in everyone's thinking, is the fact that in order to plan for a more orderly society to meet the challenge of tomorrow, consideration will have to be given to the elimination of material output wastes, as well as the satisfying of material needs.

Recognizing the importance that must be placed on the problem, this thesis is designed to augment the tools available to planners and engineers who deal with the solid waste disposal problem. Its focal point is the development of one such needed tool, an algorithm concerned with estimating the costs of collection of solid waste generated by human beings during the course of one collection period.

THESIS OBJECTIVES

The purpose of this thesis is to generate an algorithm which will enable a community planner or engineer to evaluate a communities present and/or proposed solid waste collection method and cost in an objective, consistant manner. This purpose can be expressed in terms of two specific objectives.

1. To develop and test an algorithm that can be used as a prediction equation for determing the "best cost" of a local collection procedure.
2. To further develop, refine and test such an algorithm for use as a tool in the appraisal of local collection procedures in terms of detailed costs.

STATEMENT OF PROBLEM

There are two basic considerations in solid waste collection and disposal systems for an individual community.

The first, and seemingly most important consideration from a public relations point of vie w, is that of the location of disposal sites. Satisfactory disposal sites are frequently identified by a complicated procedure involving technical examination of soils, an analysis of the sites convenience, availability of land, its cost, the tradeoffs necessary to locate the political climate and many other interrelated items too numerous to mention here.

The second consideration is that of the day-to-day operation, of which collection costs represent a national average of 80-85% (1) of the total costs for solid waste management. This thesis will be directed at the calculation of this cost, which is of paramount importance. The remaining cost, that of disposal, will not be considered at this time.

The purpose of the collection cost prediction algorithm to be described is to permit the estimation of the collection cost for an individual community.

(1) Page 3, Proceedings NATIONAL CONFERENCE ON SOLID WASTE RESEARCH - APWA December 1963

This algorithm can be used by individual communities:

1. To plan for new facilities and in making management decisions since it permits the evaluation of the cost of alternative collection methods.
2. To enable a community to evaluate its present solid waste collection method costs against a defined "best cost" generated from the algorithm.

The experimental prodecure to be described in the next section will involve the testing of real world systems against the algorithm by the substitution of data obtained from the local communities' solid waste programs as expressed in their annual budgets.

There have been s everal attempts made to develop collection costs, most related to a cost per capita or per ton of refuse collected. Among the formula are those developed in the study, "An Analysis of Refuse Collection and Sanitary Landfill Disposal:, University of California, Technical Bulletin No. 8, Series 37, December 1952. This study presents a detailed method as it pertains to refuse collection systems in man-minutes per ton, dollars per ton and several nomographs useful in the design of a refuse collection system. The publication "Refuse Collection Practice" published by the APWA, 1966, documents the results of time studies and observations, page 196-202, in several communities for the development of collection costs and refuse collection systems. A planning procedure is found on pages 437-495. Their results may be used in the development of cost figures if the particular situation fits their data.

These are several examples of the attempts to document some type of formulation needed to generate a satisfactory cost factor. Their main problem is the attempt to relate the end cost achieved to some sort of numerical base. This thesis tries to avoid relating the results of the algorithm to any specific constant. However, a total overall cost, a cost per capita and a cost per ton to collect may be developed by individual communities. Each community is different and thus will have a varying result for each of the above factors. Dependent upon their population density and road mileage, different factors will appear.

EXPERIMENTAL PROCEDURE

In order to determine community collection costs and to make meaningful comparisons among communities, a standard method is required. The following form, Exhibit I, identifies the community characteristics and collection factors common to all communities used in the algorithm. The first six (6) listed items on the form describe the physical and population characteristics of the community and should be available from the normal operating records of any taxing unit.

It is the underlying assumption of this thesis, regardless of the ultimate disposal method, that is is possible to get a reasonable approximate cost of collection for a community from; (a) the key values 1 through 6, and (b) the existing (or planned) equipment and system characteristics 7 through 14. The key values are specific for each community and serve as a point of departure for the prediction method developed.

The following six (6) items as listed in Exhibit 1 are defined as follows:

1. The Community Name: In this thesis the community name is defined as a meaningful definition of the service area. It defines the political limits within which the collection cost is to be calculated. The limits of the collection area are further defined in this thesis to mean

EXHIBIT 1

SOLID WASTE COLLECTION TIME/COST FORMULA

1. Name________________________ 2. Population________________________
3. Building Units______________ 4. Road Mileage______________________
5. No. Collections/week________ 6. Avg. Dist. to Disp.________________

7. Packer-Truck Size_____cu.yd. 8. Packer (Weight) (Compression)_____# #/cu.yd.
9. Loaders/packer______________ 10. Type Disposal____________________
11. Yearly Cost Coll.__Disp.___ 12. Generation Figure________#/cap/day
13. Packer cost/hr.____________ 14. Type Coll: Public__Contract__Pvt__

A. $\frac{\text{Population}}{\text{Dwellings}}$ = People/unit = $\frac{\#2}{\#3}$ = ________________ =

B. $\frac{\text{People/unit x \#/person/day x 7}}{\text{Collections/week}}$ = $\frac{\text{\#refuse/unit/week}}{\#5}$ (see Chart I = $\frac{\quad}{\#5}$ =

C. Packer truck volume (lbs)___(see Chart II from #7,8 or actual weight)

D. $\frac{\text{Total \#/truck}}{\text{\#/unit}}$ = No. stops/load = $\frac{C}{B}$ = __________ =

E. $\frac{\text{Building units}}{\text{Road mileage x 2}}$ = Units/side of road = $\frac{\#3}{\#4 \text{ x } 2}$ = _______ =

F. $\frac{5{,}280'}{\text{Units/side of road}}$ = Feet between units = $\frac{5{,}280'}{E}$ = $\frac{5{,}280'}{\quad}$ =

G. Select time to service stop from Chart III based on F =

H. $\frac{\text{Total \#/truck x service time}}{\text{\#/unit x 60 x \#9}}$ = Hours/load = $\frac{\text{C x G}}{\text{B x 60 x \#9}}$ = _____ =

I. $\frac{\text{Building units}}{\text{No. stops/load}}$ = Number of trips = $\frac{\#3}{D}$ = _______ =

J. Number trips x Hrs/load = Trip Hrs. = I x H =

K. Miles to disp. site from center of coll. area x 2 x 3 min./mi. x No. trips = Transport Hours = #6 x $\frac{6}{60}$ x I =

L. Trip hours + transport hours + unload x trips = Total hours/week = J + K + $\frac{15}{60}$ x I = + + x .25 =

M. Total hours/week x 52 = Total Time = L x 52 = _____________ =

N. Total time x Cost/hour = Total cost of collection = L x #13 =

the area serviced with a single truck or group of trucks under the same control. The collection system may be composed of from one to any number of routes, all serviced by a single municipal sanitation department, using the same equipment over the collection period - be it once, twice to five times a week.

2. The Population of a Community: The total number of people that live within the confines of the collection area.

3. The Total Number of Building Units - is defined as a single house with one family to a multiple house with apartments equaling the total possible stops a truck would have to make in order to collect all solid waste generated by the population.

4. The Total Road Mileage of a Community - the total road mileage of a community where building un its appear. In some cases there may be reason for deleting mileage. For example, the collection procedure may involve alley collection wherein the collection truck may travel the back yards of the building units they serve, collecting both sides of the alley at the s ame time. There may also be a section of land paralleling some road mileage where there are no pickup points due to the character of the land - farms, forests, parks, etc. This mileage may be deleted from the total at the discretion of the data

manipulator when he finds no truck routing along these roads.

5. The Total Number of Collections Per Week - the total number of collections per week affect the truck carrying capability. As the number of collections per week increases the weight of refuse per stop decreases and the number of pickups possible per truck, per trip increases requiring fewer trips to the disposal site on a given day. Also, as the number of collections per week increases, it may be necessary to add trucks; thus increasing the total collection cost.

6. Average Distance to the Disposal Site - this distance adds to the total overall time of collection, as the distance increases, as it is necessary to empty the truck when full and it takes a period of time to reach the disposal site before unloading.

The above listed six characteristics must be known in order to determine an estimated cost. Assumptions usually must be made for characteristics seven through fourteen, which follow. However, there may be a number of these last characteristics peculiar to local circumstances that are known. This knowledge helps in the determinations of a more accurate cost estimate.

These characteristics are defined as follows:

7. Packer Size - It is necessary to fix the packer truck (the vehicle used to collect and transport solid waste) size in cubic yards if one is owned by a community or to assume a size if none is available. Packers run in several sizes (16 to 24 cubic yards). Selection of packer size is dependent upon the topography, road limitations, distance to travel between pickup points and several other factors; it may be necessary to simulate use of several different sizes to determine the minimum cost. The typical packer truck size used in the algorithm is 16 cubic yards.

8. Packer Compression - Weight - It is necessary to have the total weight handled by a packer truck in order to calculate the number of services a truck can handle. The weight may be obtained from either of two sources. First, if the packer compression is known, the use of the appropriate line in Chart II will give an approximate total load weight. Second, the weight handled may be obtained through the averaging of several actual truck weighings.

9. Loaders/Packer - It is necessary to determine the number of men who act as loaders on the packer truck, as the time element required per pound of solid waste to load the packer truck, is directly related to the number of loaders available.

10. Type Disposal - It is assumed that the collection system will discharge waste into a disposal system; such

as a landfill, an incinerator or transfer station. Truck unloading time may vary among the different types of disposal systems. A time of .25 hours has been assumed on the average to unload a full compactor truck. This constant is used in equation L.

11. Yearly Cost - This figure is usually available for both collection and disposal if the municipality contracts or makes its own collection. If available, it should be used only as a comparison figure for the results calculated.

12. Generation Figure - A local figure of generation is required if total weight of solid waste to be handled is found. Through previous work in this area (Eastern Pennsylvania), this figure has been calculated to be approximately 2.5 pounds per person per day of household waste. See Chart I.

13. Packer Cost Per H our - This figure is needed to determine the total cost of collection. If it is not available, a figure composed of the driver's hourly rate, the loader's hourly rate and a figure for maintenance and gas and depreciation may be developed as an assumption. See Appendix A.

14. Type of Collection - Check whether the collection is made by public agency, by contract or a private contractor.

With both the first six characteristics known and characteristics seven through fourteen determined, it is possible to estimate an approximate cost for collection by the following procedure:

A. The population (# 2) is divided by the total building units (# 3) to determine the average number of generators per unit (A).

B. The generators per building unit (A) is divided by the number of collections desired per week (# 5) and multiplied by the selected pounds per person per day (# 12) times seven days to determine the total average poundage (B) per building unit collection.

C. The total weight a packer truck can hold (# 8) is found by either the use of chart II, knowing the compression and volume, or from the actual weight (C) as found by a weight sample.

D. The total truck weight (C) divided by the calculated pounds per building unit per collection period (B) equals the number of stops per truck load or the total number of stops (D) possible before the truck is filled.

E. The total number of building units (3) divided by the total road mileage (4) times two (building units exist on both sides of a road) equals the total number of building units (E) per mile of road.

EXHIBIT 2

SOLID WASTE COLLECTION TIME/COST FORMULA

1. Name ______ 2. Population 1650

3. Building Units 476 4. Road Mileage 9.8

5. No. Collections/week 1 6. Avg. Dist. to Disp. 1.0

7. Packer-Truck Size 16 cu.yd. 8. Packer (Weight) 10,000 # (Compression) ____ #/cu.yd.

9. Loaders/packer 2 10. Type Disposal LANDFILL

11. Yearly Cost Coll. \$2500 Disp. \$500 12. Generation Figure ____ #/cap/day

13. Packer cost/hr. Est 8^{50} 14. Type Coll: Public__ Contract__ Pvt__

A. $\frac{\text{Population}}{\text{Dwellings}}$ = People/unit = $\frac{\#2}{\#3}$ = $\frac{1605}{476}$ = 3.4

B. $\frac{\text{People/unit x \#/person/day x 7}}{\text{Collections/week}}$ = $\frac{\text{\#refuse/unit/week}}{\#5}$ (see Chart I) = $\frac{60}{\#5}$ =

C. Packer truck volume (lbs) 10,000 (see Chart II from #7,8 or actual weight)

D. $\frac{\text{Total \#/truck}}{\text{\#/unit}}$ = No. stops/load = $\frac{C}{B}$ = $\frac{10,000}{60}$ = 167

E. $\frac{\text{Building units}}{\text{Road mileage x 2}}$ = Units/side of road = $\frac{\#3}{\#4 \times 2}$ = $\frac{476}{9.8 \times 2}$ = 24.3

F. $\frac{5,280'}{\text{Units/side of road}}$ = Feet between units = $\frac{5,280'}{E}$ = $\frac{5,280'}{24.3}$ = 217'

G. Select time to service stop from Chart III based on F = 1.89

H. $\frac{\text{Total \#/truck x service time}}{\text{\#/unit x 60 x \#9}}$ = Hours/load = $\frac{C \times G}{B \times 60 \times \#9}$ = $\frac{10,000 \times 1.89}{60 \times 60 \times 2}$ = 2.61

I. $\frac{\text{Building units}}{\text{No. stops/load}}$ = Number of trips = $\frac{\#3}{D}$ = $\frac{476}{176}$ = 2.7

J. Number trips x Hrs/load = Trip Hrs. = I x H = 2.7 x 2.6 = 7.0.

K. Miles to disp. site from center of coll. area x 2 x 3 min./mi. x No. trips = Transport Hours = #6 x $\frac{6}{60}$ x I = 1.0x.1x3=0.3

L. Trip hours + transport hours + unload x trips = Total hours/week = J + K + $\frac{15}{60}$ x I = 7.0 + 0.3 + 3 x .25 = 8.0

M. Total hours/week x 52 = Total Time = L x 52 = 8.0 X 52 = 416

N. Total time x Cost/hour = Total cost of collection = L x #13 =

416 x 8.50 = \$3500.00

F. The total building units per mile of road (E) divided into 5,280 feet per mile gives the total number of feet (F) between pickups.

G. A time per pickup (G) is determined from Appendix B (Chart III) based upon the answer given in F.

H. The total poundage per truck load (C) times the service time per stop (G) divided by the pounds per building unit (B) times 60 minutes per hour times the number of loaders per packer (#9) equals the total time in hours (H) required to load a packer.

I. The total building units (#3) divided by the number of stops per load (D) equals the total number of trips (I) required. Round out to the next highest number.

J. The number of trips (I) times the hours per load (H) equals the total number of trip hours (J) required to load all the collection area.

K. The average miles to the disposal site (#6) from the center of the collection area times two (round trip mileage) times an average of 20 mph or 3 minutes per mile times the number of trips calculated (I) to collect the area equal the total number of transport hours (K) to the disposal site.

L. The total trip hours (J) plus the total transport hours (K) plus the number of trips (I) times a factor of .25 hours (required to unload) equals the total hours (L) required.

to collect the solid waste from the area.

M. The total hours (L) times 52 weeks/year equals the total hours per year (M) to collect solid waste.

N. The total hours (M) required to collect times the cost per hour (#13) equals the total collection cost (N).

SOURCES OF INFORMATION FOR COST FORMULA

The information for the physical and population characteristics of a community, # 1 through # 6, must be obtained before any algorithm manipulation can be made. To obtain the data necessary to fill out the form, Exhibit 1, it was necessary to contact several sources. For the purposes of the thesis the information for physical and population charac teristics, # 1 through # 6, were obtained in the following manner from the sources documented.

Item 1. The Community Name - The name of the community or are a whose collection cost is to be estimated.

Item 2. The Population - The population may be obtained from a number of sources, among them are the U.S. Census, School Districts, Local Planning Boards and some State H ighway Departments (who use it for the reimbursement of state funds for road work).

Item 3. Building Units - A count of the building units may be obtained from the municipality tax records, planning reports or from a local utility such as the telephone company, gas company or electrical power company.

Item 4. Road Mileage - The total road mileage including both local and state roads may be obtained from the municipal records (the Engineers Office) or the State Highway Department.

Item 5. Number of Collections Per Week - The number of collections per week may be obtained through personal contact with community officials or assumed.

Item 6. Average Distance to Disposal Site - This distance may be obtained from local community officials or by finding the nearest site to which refuse is taken and assuming a center point of the community and measuring the mileage.

All of the above information may be found to some degree in all communities by personal contact with the community public officials. It has proven somewhat difficult in the smaller community to find an official who knew the answers to every question; thus, it was necessary to contact several people to complete the data required.

RESULTS

1. In all cost estimating, the general rule is to be as accurate as the situations demand. The observed differences of total cost results cannot really be made the subject of rigorous statistical examination because there is no previous experience. However, this thesis is exploratory in nature, and the results do indicate that the algorithm can, in fact, be useful.

2. The algorithm has been applied to 20 communities, of less than 11,000 population, using only the first six characteristics as known inputs. The same basic parameters (characteristics seven through fourteen) have been used. The algorithm results were found to be within plus or minus 20% accuracy in 17 of 20 cases (See Table 1, abridged and Table 2.)

3. The algorithm as developed and presented seems to be a satisfactory procedure for the development of an approximation of an overall cost for a community solid waste collection system. The procedure as set up is easily handled on a local basis and the use of local knowledge should help refine the estimate and achieve a higher degree of accuracy.

4. The data needed to apply the algorithm are available, although often not easily found. Every community has in its files or can obtain the data needed. Personal contact to evaluate characteristics 7-14 leads to a sig-

nificant improvement in the accuracy of the cost estimate. Calculations may be made without such personal contact but may not reflect the accuracy which might be obtained through personal contact.

5. The application of the algorithm has shown that some communities have ignored several important costs. This appears to indicate a lack of appreciation of a total cost system and leads to the development of misleading figures for the cost of operations. At this time there is no standard method of accounting for all communities.

COMMENTS ON RESULTS

The basic sost factor used, Number 13, which by a change in its composition to include or exclude a cost, influences the total cost outcome to a large degree. This is demonstrated in several instances where the thesis algorithm using the assumed data computes a cost that is over the actual budget figure reported. A check with the operating authorities indicates that the predicted packer-truck cost per hour was based upon a cost figure supplied by the community which did not take maintenance of equipment into account. After substituting the reported community cost per hour figure, the thesis results vs. the actual reported costs resulted in a figure much closer to the budget one. The community had taken only the wages of the driver and loader and had ignored the truck maintenance costs.

The neglect of considering equipment maintenance creates a false fiscal picture; indicating frequently, that a public collection system is a more economical method of operation.

There are illustrated (#19 and #20) two examples of private collections. In one, a single collection per week is offered. Based upon the standard yearly fee, there is a notably large profit potential. In the other, two collections per week are offered. For the standard area collection fee, a more reasonable profit potential (from the householder point of view) is possible. These figures have not been confirmed and are pure conjecture based upon all available evidence.

CONCLUSIONS

1. It is possible to use the algorithm to estimate total collection cost with a reasonable degree of accuracy.

2. The algorithm may be used as a diagnostic tool to point out peculiar local practices in community solid waste accounting and collection procedures. This may be done in detail.

3. The collection costs vary primarily by community population density and road mileage and it is not feasible at this time to develop a standard cost per capita.

4. No comparable research has been found against which to test the thesis results.

5. The algorithm may be used to test the cost effectiveness of different methods and collection practices.

6. The procedure as outlined is a tool that will assist interested parties in reproducing the experiment to obtain data in their area.

FIELDS FOR FURTHER STUDY

1. This study has concerned itself with communities whose population was below 11,000. Further study should be undertaken in communities of larger populations to determine the affect that apartment type pickups will have on the overall cost of collection.

2. The thesis deals only with the collection of household solid waste refuse. In most of the communities checked, a very minimum of commercial waste was collected and no industrial waste was collected at all. Study of the affect that larger amounts of commercial waste would have on the overall system should be made.

3. Of the total solid waste problem of collection and disposal, this thesis has developed only a collection procedure algorithm. Collection costs represent approximately 80% of the total disposal costs. Disposal, however, is a very important part of the total picture and should be considered in any future work because of the potential environmental problem created by improper operations.

4. The study was conducted in four counties and waste collection procedures may differ from section to section. Analysis of data obtained from other areas would be helpful in developing the overall value of the algorithm.

5. No allowance has been made in the algorithm for truck time to get to its route, return to the garage at the

end of the day or the inclusion of eating lunch on the route. These factors may affect the ultimate cost and should be considered in further work.

APPENDIX A

PACKER-TRUCK COST/HOUR (CHARACTERISTIC #13)

A packer-truck cost per hour factor has been developed for use in the algorithm. The communities tested were selected on the basis of having used public funds to either operate a public collection and disposal system or to contract for the disposal of waste through a private contractor.

The algorithm was applied to 20 communities varying in population from 530 to 11,000 inhabitants. Both public and private collection were included in the test communities. The cost per hour factor developed for the algorithm and used in equation included the following factors:

Driver Wage	$2.50 per hour
Loader Wage	2.25 per hour
Truck Maintenance	1.50 per hour
Truck Depreciation	1.50 per hour

Cost Factors

Public Collection - 1 driver, 1 helper	$6.25 per hour
Private Collection - 1 driver, 1 helper	7.75 per hour
Public Collection - 1 driver, 2 helpers	8.50 per hour
Private Collection - 1 driver, 2 helpers	10.00 per hour

APPENDIX B

SERVICE STOP TIME FORMULATION (CHARACTERISTIC G)

Assumptions:

The compactor truck drives down one lane of the road to be loaded from either side with 3.0 cans per pickup point.

Time Standards:

Walking at regular pace of 2.5 mph	= 0.0046	min/ft.
Walking loaded at a pace of 2.0 mph	= 0.0054	min/ft.
Empty can in truck (Note 1)	= 0.15	min/can
Compaction time (Note 1)	= 0.15	min/can

Apply 10% Fatigue and unavoidable delay
5% Personal time

Walk from street to can 10 ' x 0.0046	= 0.046
Walk with can to truck 3 x 10' x 0.0054	= 0.162
Empty cans in compactor 3 x 0.15	= 0.450
Walk empty back to storage 3 x 10' x 0.0054	= 0.162
Compactor time 3 x 0.12	= 0.360
Total	1.180
Plus 10% (Fatigue, unavoidable time)	0.118
	1.298
Plus 5% (Personal time)	0.065
Curbside pickup Total	1.363

For each 10' between pickups add 0.05 min.

Driving speed equals 20 mph or 0.00066 min. per foot.

For collection distance between pickup point of over 100', the helper must ride; therefore, to the time of 1.81 minutes, add a factor of 0.07 for each 100 additional feet.

Example:

1000' equals 900' x 0.07 plus 1.81 equals 2.43 minutes.

Note 1:

Data for equation is found in a report of work in a study done by the Department of Industrial Engineering, North Carolina State, dated May 11, 1964, C. A. Anderson, under PHS Grant 1-D01-UI-00050.

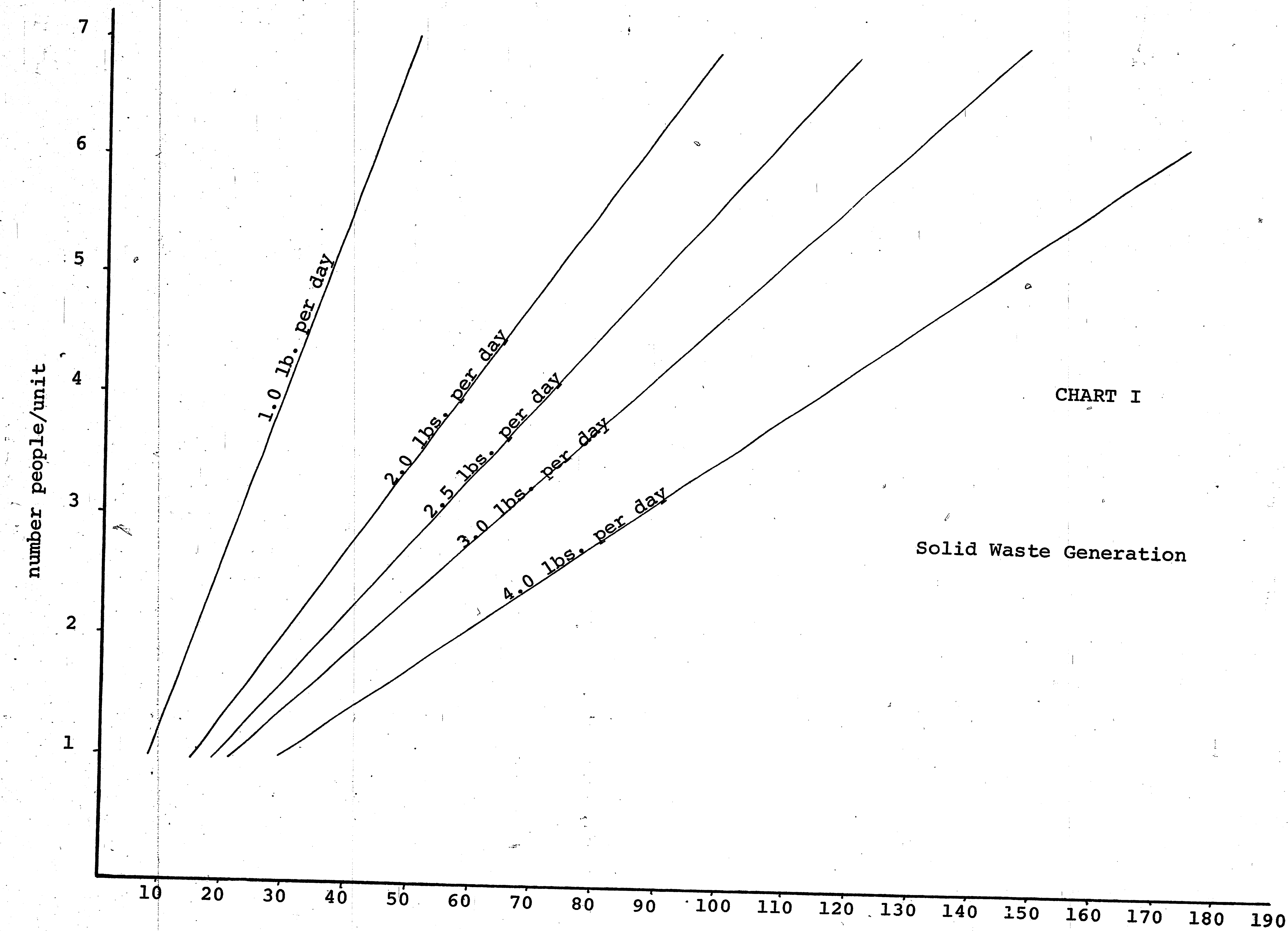

CHART I

Solid Waste Generation

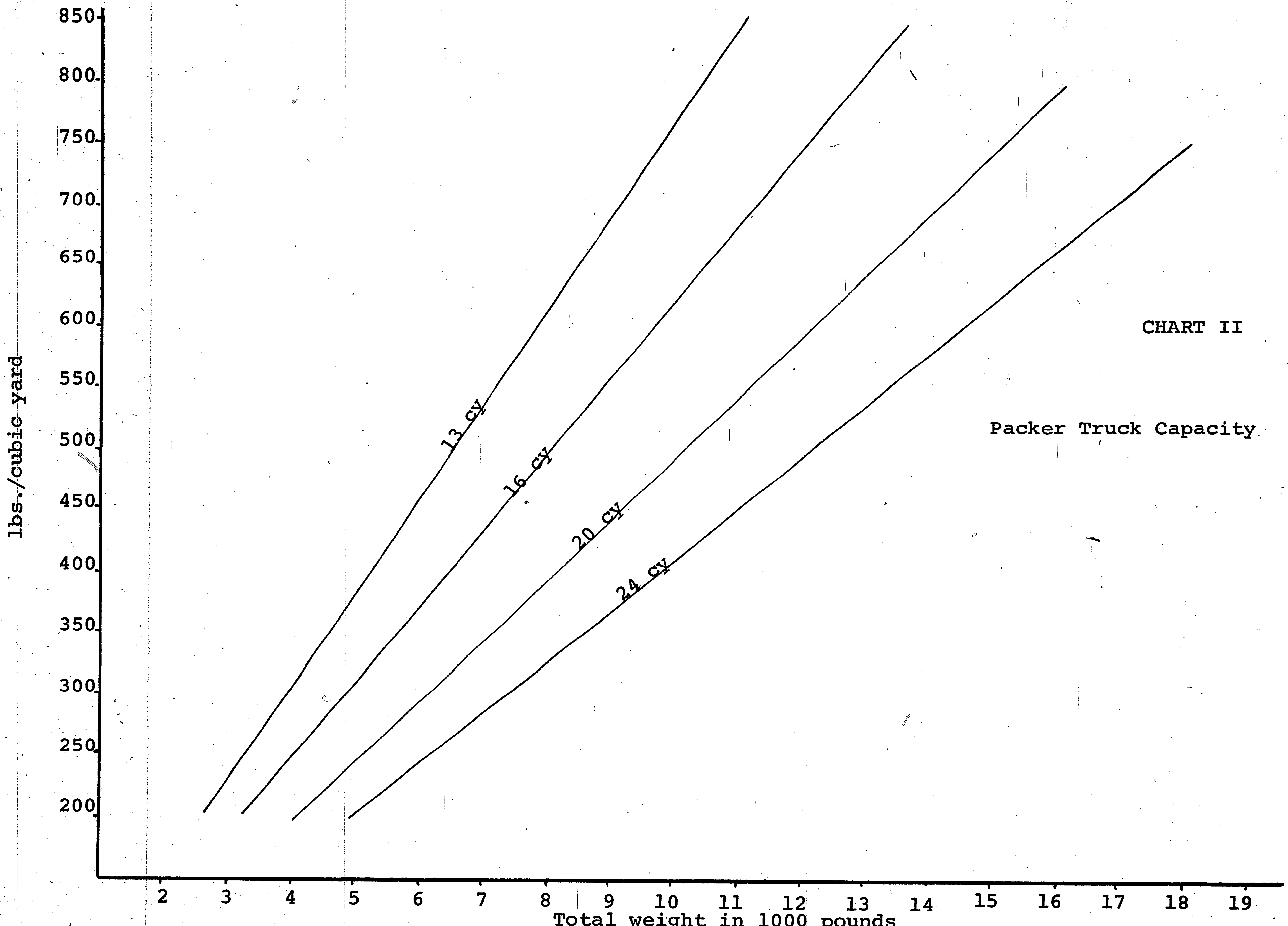

CHART II

Packer Truck Capacity

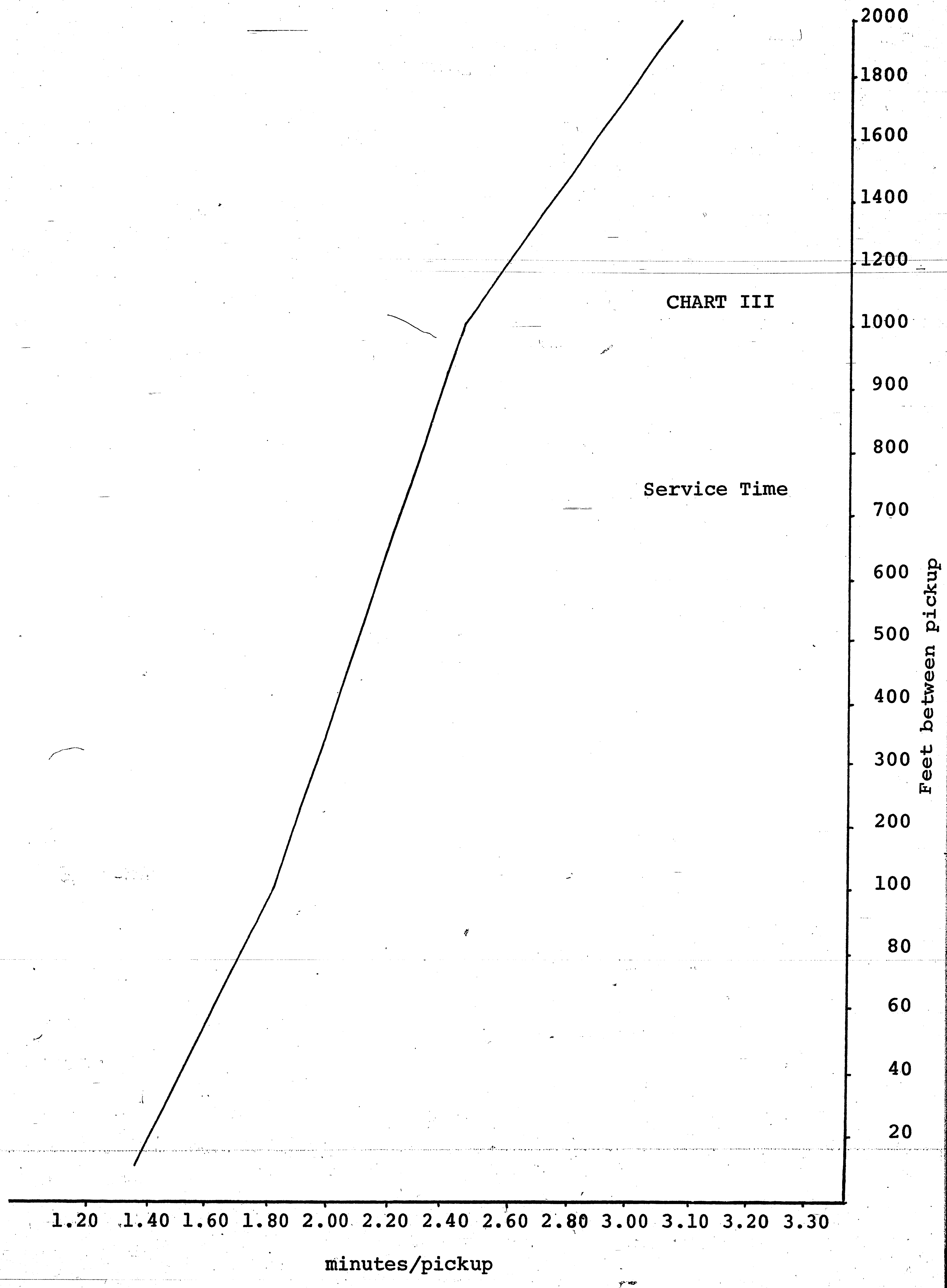
CHART III
Service Time
Feet between pickup
2000
1800
1600
1400
1200
1000
900
800
700
600
500
400
300
200
100
80
60
40
20
1.20
1.40
1.60
1.80
2.00
2.20
2.40
2.60
2.80
3.00
3.10
3.20
3.30
minutes/pickup

TABLE 1 (ABRIDGED)

	#2 Community Population	#3 Building Units	#4 Road Mileage	A People Per Unit	M Estimated Total Cost	#11 Community Budgeted Cost	Variance
1	5,260	1,775	20.0	3.30	13,800	14,625	- 8
2	1,460	444	7.0	3.37	4,670	4,000	+ 15
3	960	304	5.5	3.15	2,750	3,300	- 17
4	1,590	463	8.3	3.43	4,600	4,000	+ 15
5	530	151	4.7	3.50	1,260	1,400	- 10
6	7,000	2,100	24.0	3.33	15,600	16,500	- 5
7	1,110	308	60.1	3.61	3,700	4,000	- 8
8	8,590	2,604	26.7	3.04	21,600	19,000	+ 14
9	2,740	821	7.9	3.34	8,060	7,111	+ 8
10	3,350	1,110	13.4	3.00	9,370	10,080	- 7
11	1,670	479	8.5	3.50	4,470	4,000	+ 12
12	745	211	4.6	3.50	2,330	1,800	+ 29
13	3,170	992	115.2	3.20	22,700	19,000	+ 19
14	1,605	476	9.8	3.40	3,500	2,500	+ 40
15	2,770	839	54.0	3.30	9,000	9,600	- 6
16	1,150	370	5.7	3.10	2,830	2,800	+ 1
17	9,200	2,665	17.5	3.45	44,200	42,500	+ 4
18	1,180	360	5.5	3.30	4,000	3,536	+ 13
19*	9,500	2,700	135.0	3.50	59,500	Est. 62,800	- 5
20*	11,100	3,700	60.0	3.00	38,500	76,500	- 96

* Private collectors no municipality contract for collection

Table 2

Per Cent Error Distribution Chart

```
                              x                    x
                              x                    x
                              x                    x
                              x    x   x           x             x
 x*        x        0         x    x*  x     x     x      x      x
_____________________________________________________________________
over  -20%    -15%    -10%     -5%   0   5%   10%   15%   20%   over
-20%                                                            20%
```

* Private operator not under contract

15 of the 20 samples fall between ± 15%

17 of the 20 samples fall between ± 20%

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VITA

Robert C. Porter

3018 Fischer Road

Easton, Penna. 18042

Date of Birth - December 1, 1925

Place of birth - Brooklyn, New York

Name of Parents - Gertrude and George Porter

Married - 3 children

Education - Summit High School - 1944
Lafayette College - BS in AE, 1950

Employment-

6/50 9/56 Time Study Engineer and Incentive Supervisor
Mack Printing Company, Easton, Pa.

9/56 6/65 Sr. Industrial Engineer
American Can Co., Easton, Pa.

6/65 1/68 Partner - McNeal & Porter, Consulting Engineers
Civil and Industrial Engineers

7/67 present Solid Waste Project Coordinator

Tocks Island Regional Advisory Council
Stroudsburg, Penna.

Registered Professional Engineer (IE) State of Penna. 1957
State of New Jersey 1966

Registered Surveyor State of Penna. 1967